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Common Materials for Emergency Respiratory Protection: Leakage Tests with a Manikin

DOUGLAS W. COOPER, WILLIAM C. HINDS, JOHN M. PRICE, ROBERT WEKER and HOWELL S. YEE
Harvard University, School of Public Health, Department of Environmental Science and Physiology, 665 Huntington Avenue, Boston, MA 02115

In areas where respirators are not routinely used, emergencies (such as fires) may occur in which protection from airborne particles is necessary. The following readily available materials were tested on a manikin connected to a breathing simulator to determine the fraction of an approximately 2-μm diameter aerosol that would leak around the seal between the materials and the manikin's face: cotton/polyester shirt material, cotton handkerchief material, toweling (a wash cloth), a surgical mask (Johnson & Johnson Co., Model HRI 8137), and a NIOSH-approved disposable face mask (3M Corp., Model #8710). The leakage tests were done to supplement the measurements of penetration through the materials reported previously. Leakage fractions were determined by comparing the penetration of the same aerosol for the materials held to the face versus being fully taped to the face. At a breathing rate of 37 liters per minute, mean leakages for the materials ranged from 0.0 percent to 63 percent, depending on the material. Mean penetrations exclusive of leakage ranged from 0.6 percent to 39 percent. Use of nylon hosiery material ("panty hose") to hold the handkerchief material or the disposable face mask to the face was found to be very effective in preventing leakage. Such a combination could be expected to reduce leakage around the handkerchief to about 10 percent or less in practice, and around the mask to less than one percent, which suggests the adaptation and use of such an approach for industrial hygiene.

Introduction

This is an extension of our previous work[1] on evaluating readily available materials for use in providing expedient respiratory protection in case of the accidental release of aerosols, due to such situations as fires, explosions, chemical spills, nuclear reactor malfunctions, *etc.*

Earlier investigations on expedient respiratory protection[2,3] used polydisperse aerosols of bacterial spores to determine the average penetration plus leakage, as measured by particle number count. Penetration plus leakage is the total fraction of the aerosol number concentration outside the mask that reaches the inside of the mask in two different ways: penetration is the fraction of particles of a given size which pass through the material; leakage is the fraction of the flow which passes through the gaps in the seal between the mask and the face. Our previous study[1] determined penetration of these materials at three face velocities (1.5, 5.0, 15 cm/s) as functions of particle (aerodynamic) diameter. The results were also presented in terms of the quality factor,

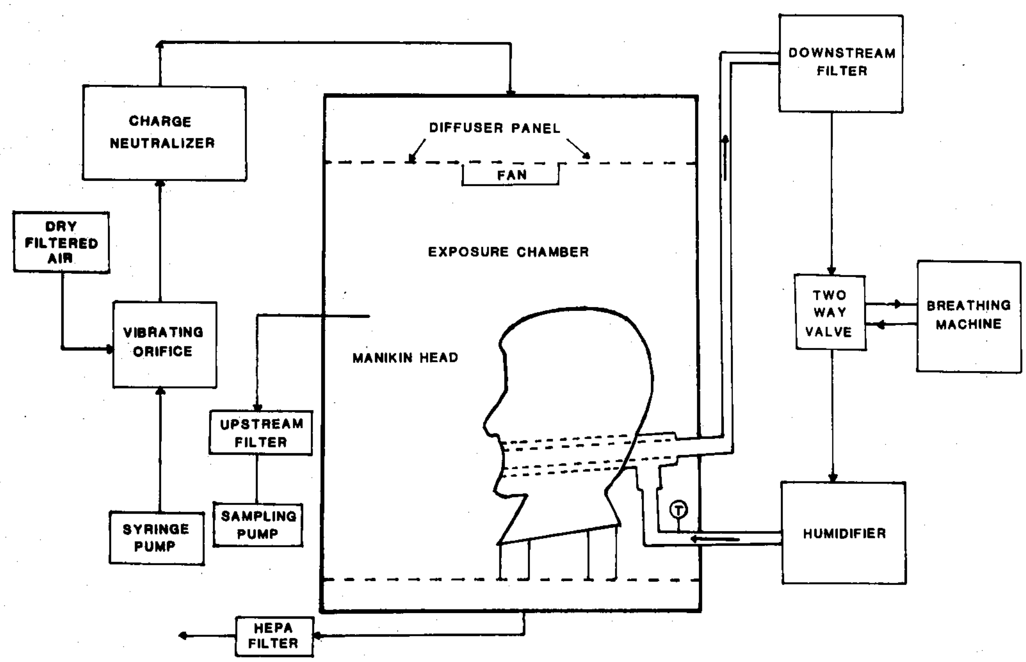

Figure 1 — Schematic flow diameter.

TABLE I
Test Materials

1. Single-use respirator mask, 3M Corporation Model #8710.
2. Handkerchief - white broadcloth 100% cotton 66/in. by 58/in. thread count.
3. Washcloth - terryweave 88% cotton, 12% dacron (RN-15964) polyester.
4. *Oxford shirt material* - 65% fortel polyester, 35% cotton, 46 in. by 46/in. thread count.
5. Surgeon's mask - disposable Johnson and Johnson Model #HRI 8137.
6. Women's nylon hosiery ("panty hose")

q, the reciprocal of the pressure drop across the material multiplied by the natural logarithm of the penetration:

$$q = (1/\Delta P)ln(Pn) \quad (1)$$

in which Pn is the ratio of the number concentration downstream from the material to that upstream. Extrapolated to a pressure drop we deemed acceptable (50 Pa, 0.2 in. of water, 0.5 cm of water), the materials tested gave, at 1.5 cm/s, penetrations of particles of 1-μm diameter ranging from 0.004 to 0.88.

In practice, the concentration within the face mask would be greater than the product of the penetration times the concentration outside the mask, because of leakage through gaps in the seal of the mask to the face. Leakage values measured for a set of face masks (half-mask respirators) were summarized by Leidel.[4] Median values ranged from 0.04 percent to 0.5 percent for three different models, tested on a 35-person anthropometrically weighted panel.[4,5] The goal of the present study was to determine the leakage for the materials we studied previously, with the addition of the surgeon's mask (Johnson & Johnson Co., Model #HRI 8137), readily available at drugstores, and the deletion of the sheet material, which was less effective than the other materials tested.

Experimental Apparatus and Procedure

Apparatus

Figure 1 shows the set-up schematically. A Thermo-Systems Incorporated (TSI) Model 3050 vibrating orifice generator was used to generate a monodisperse di-octylphthalate (DOP) aerosol (diameter: 1.8 μm) for challenging the test respirators. The DOP aerosol, tagged with 5 percent by weight fluorescein, passed through a TSI Model 3054 charge neutralizer before entering the exposure chamber. Flow in the chamber passed through a diffuser panel past a paddle wheel circulating fan to ensure that the aerosol was evenly distributed throughout the exposure chamber. The flow left the chamber through the bottom diffuser panel to an exhaust line and high efficiency particulate air (HEPA) filter. A manikin head was placed in the center of the exposure chamber to provide a fairly realistic method of holding the test respirators. The materials tested are listed in Table I. The methods of holding test respirator material on the manikin face were: a) completely seal all the edges with plastic (PVC) tape over the nose, around the cheeks, and under the chin; b) loosely hold the material on with four pieces of PVC tape on the corners of the mask (one on each cheek and one under each side of the chin) or hold by the straps provided on the commercial respirators; and c) hold to the face by a nylon support hosiery material ("panty hose") covering the entire manikin head (Figure 2). The manikin was a U.S. Army design, used in testing military respirators, such that the facial features are based upon an average male. In addition, we covered the painted plaster material of the manikin by painting a thin film of PVC plastisol to provide a more skin-like surface.

The manikin was connected to an apparatus which mechanically simulated the breathing of a worker during a moderate level of activity. The volume of air inhaled in a minute ("minute volume") was 37 L; the respirator rate was 23 cycles per minute, having a breathing rate profile closely approximating that indicated by Silverman *et al.*[6] for a work rate of 622 kg-m/min, 101 watts. The breathing machine drew the air through the manikin mouth, through a downstream absolute filter, and then through a check valve system into the breathing machine double-piston system. On exhalation, the air was pushed out of the pistons through the outlet side of the check valve system through a humidifica-

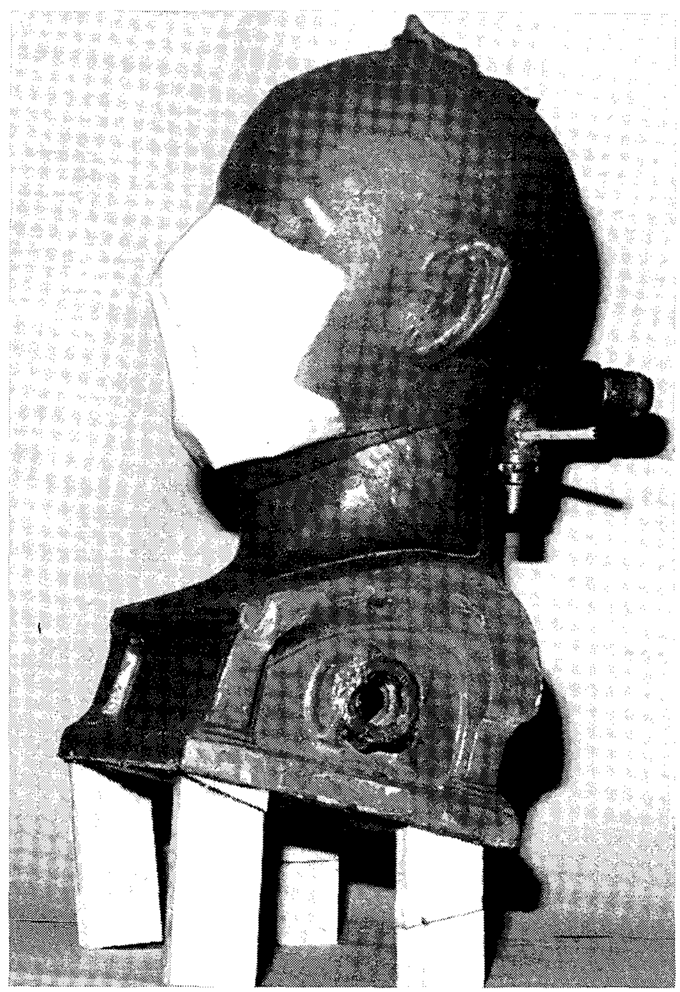

Figure 2 — Photograph of manikin with fabric held to face by nylon hosiery.

TABLE II
Means and Standard Errors for Leakage Plus Penetration and for Pressure Drop

Material (# layers)	Attachment Method	Leakage Plus Penetration Mean ($\overline{Pn}$) (%)	Leakage Plus Penetration Standard Error	Pressure Drop at 37 L/min (N/m^2) Mean	Pressure Drop at 37 L/min (N/m^2) Standard Error
3M - #8710 (1)	nylon hosiery	0.58	0.18	41.	0.8
3M - #8710 (1)	fully taped[A]	1.5[B]	0.24	42.	0.8
3M - #8710 (1)	strapped	19.[B]	2.5	28.	0.0
J&J - #HRI 8137 (1)	fully taped[A]	4.2	0.8	28.	2.2
J&J - #HRI 8137 (1)	tied	36.	4.9	21.	2.2
Shirt - Oxford cloth (4)	fully taped[A]	31.	1.0	27.	3.0
Shirt - Oxford cloth (4)	corners taped	74.	5.0	11.	0.8
Handkerchief (4)	fully taped[A]	24.	3.1	35.	3.8
Handkerchief (4)	corners taped	68.	4.5	11.	1.9
Handkerchief (4)	nylon hosiery	28.	3.0	34.	2.2
Toweling - washcloth (1)	fully taped[A]	39.	1.0	19.	3.0
Toweling - washcloth (1)	corners taped	60.	5.5	8.	0.8
Toweling - washcloth (2)	corners taped	30.	1.8	18.	4.4

[A]Material taped completely around periphery, which is not how it would be used in practice.
[B]Four tests - all others are mean leakage plus penetration from three tests.

tion system, which raised the air temperature to 37°C ± 1°C and raised the relative humidity to 97% ± 3%. The air exited the manikin mouth through a separate tube that encircled the inhalation tube, and the air then flowed back out through the mask.

The upstream absolute filter sampler was located in the chamber wall perpendicular to the axis of the manikin's mouth 13.3 cm above the mouth, 27.3 cm from the axis.

Test Procedure

The manikin inhalation and exhalation tubes as well as the face area were washed with distilled water to remove any fluorescein material left from previous tests. A fresh respirator mask was applied to the manikin, and the manikin was placed inside the exposure chamber and attached to the breathing machine. The aerosol generator was started and 15 minutes allowed to pass, to bring the chamber aerosol concentration to equilibrium. Absolute filters were placed into the prewashed upstream and downstream filter holders. Then the breathing machine and upstream sampler were run simultaneously for 30 minutes. After sampling was completed, the aerosol generator was shut off, and the sampler filters removed for fluorescein analysis to determine DOP mass concentrations upstream and downstream of the test respirator. For subsequent tests the used test respirator was removed, the washing procedure repeated, and a fresh respirator mask applied to the manikin for testing.

To determine the pressure drop across each test respirator, the test respirator was applied to the manikin and the resistance pressure drop measured, at a constant flow rate of 37.3 liters per minute (L/min), with a U-tube manometer.

TABLE III
Leakage Estimates

Material	Number of Layers	Mean Penetrations (%) Not Fully Taped	Mean Penetrations (%) Fully Taped	Leakage (%) Mean[A]	Leakage (%) 95% C.I.[B]
3M - #8710 + Nylon Hosiery	1	0.6	1.5	-1.	-1.6, -0.2
3M - #8710	1	19.	1.5	17.	9, 25
J&J - HRI 8137	1	36.	4.2	33.	11, 56
Shirt (Oxford)	4	74.	31.	63.	31, 95
Handkerchief	4	68.	24.	58.	35, 80
Handkerchief + Nylon Hosiery	4	28.	24.[C]	5.4	-13, 23
Toweling (Washcloth)	1	60.	39.	34.	-4, 74
Toweling (Washcloth)	2	30.	15.[D]	18.	

[A]Corrected difference in penetrations. See text.
[B]Corrected confidence intervals for differences in mean penetrations. See text.
[C]Assumed to be the same as without nylon hosiery.
[D]Assumed to be the square of the penetration (0.39) of the single-layer when fully taped.

TABLE IV
Comparison Between Manikin Tests and Previous Tests

Material	Number of Layers	ΔP (N/m^2)	V (m/s)	Measured Penetration $\overline{Pn}$	Expected Penetration[A] at V=.015 m/s	Expected Penetration[A] at V=0.05 m/s
3M #8710	1	42	0.025	0.015	0.0005	0.088
Shirt	4	27	0.030	0.31	0.43	0.80
Handkerchief	4	35	0.037	0.24	0.47	0.61
Toweling (Washcloth)	1	19	0.032	0.39	0.18	0.62

[A] *Pn = exp (-qΔP), where q is a quality factor, determined in the previous work.*

The measurements were corrected for the manikin flow resistance measured without a test respirator.

A stock solution of 5 ppm DOP and 0.25 ppm fluorescein was prepared in 2-propanol. This solution was used to generate the test aerosol and also to prepare a standard curve. Samples of the test aerosol were collected on filters and then extracted. The 47-mm-diameter filters were formed by cutting them with a steel die from sheet stock of Mine Safety Appliances (Pittsburgh, PA) 1106-B all-glass filter paper with organic binder. To minimize contamination, the filters were pretreated with ethyl alcohol using a Buchner funnel-filtering flask set-up, then allowed to air dry. The extraction was done as follows: ten mL of extracting-diluting solution ($NaOH/NaHCO_3$ buffer and water) were added and the solutions "ultrasonicated" 2 to 5 minutes. Each solution was filtered through a new 0.2-μm Nuclepore filter to remove glass fibers dislodged during the "ultrasonication." The filtrate was collected directly in the cuvette for fluorescence measurement, the first mL being used to rinse the cuvette, then discarded. The fluorescence of the extract was measured and the fluorescein concentration determined by comparison with a standard curve. The latter was prepared by measuring the fluorescence of serial dilutions of the stock solution. Because the fluorescence of fluorescein is maximum and its variability is minimum at pH values near 10.6, an appropriately buffered alkaline solution was used to extract the filters and to prepare the diluted standards. Concentrations of DOP aerosol were inferred by determining the concentration of the fluorescent tracer. Linear regression analysis was performed for standards ranging from zero (buffer extraction solution) to 100 ppb fluorescein. This method can detect as little of 0.1 ng fluorescein in 1 mL of solution and is linear up to about 1000 ng fluorescein in 1 mL. Both the DOP and the fluorescein are chemically stable and of low vapor pressure, so their ratio in the aerosol can be expected to be effectively constant.

Results

Measurements of concentrations in the chamber were made repeatedly during operation of the system. The concentrations were measured typically with a standard deviation of about 4 percent of the mean concentration, a coefficient of variation of 0.04. The coefficient of variation of the ratio of two such concentration measurements would be about 0.06, and this is the coefficient of variation of the penetration values one would expect if the only contribution to error came from the concentration measurements.

Table II summarizes the most important results. Penetration plus leakage is the ratio of the concentration downstream from the mask to that in the chamber. The standard error of the mean is the standard deviation divided by the square root of the number of measurements (usually 3) making up the mean. Of the fully taped conditions, only the 3M mask and the Johnson and Johnson mask allowed less than 20 percent of the 1.8-μm diameter particles to penetrate. The mean values of leakages plus penetrations for the masks and the household materials, when neither fully taped nor held on with the nylon hosiery, ranged from 19 percent to 74 percent. The panty hose material was readily penetrated (98 percent) by the 1.8-μm particles, but when it was used with the 3M mask or with the handkerchief, the nylon material succeeded in reducing leakage. This is discussed below.

The mean pressure drops for the fully taped materials ranged from 19 N/m^2 to 42 N/m^2, in comparison with the level of 50 N/m^2 (0.5 cm of water) selected by us as an upper value for comfortable use. The U.S. Federal certification

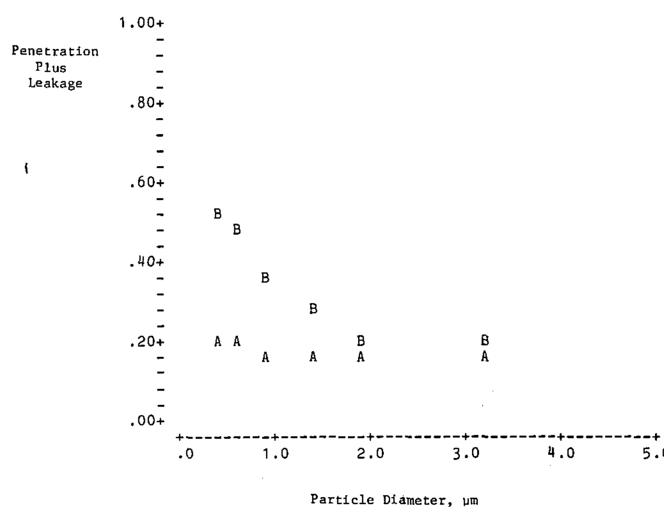

Figure 3 — Estimated penetration plus leakage of 3M #8710 mask at 50 Pa pressure drop at 0.015 (A) and 0.05 (B) m/s face velocities versus particle diameter.

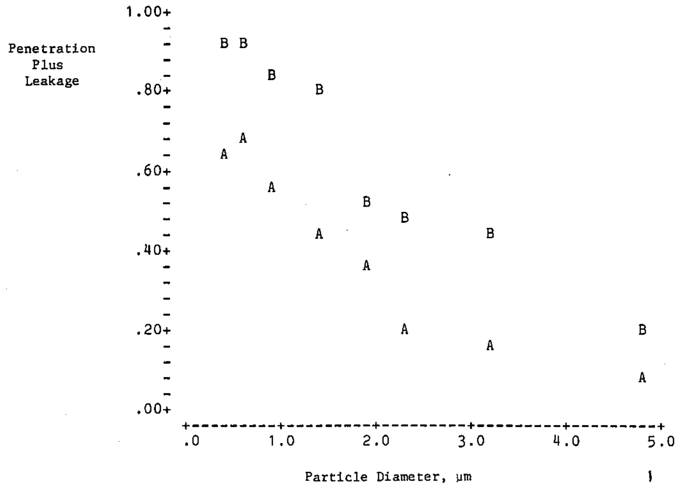

Figure 4 — Estimated penetration plus leakage of handkerchief/nylon hosiery combination at 50 Pa pressure drop at 0.015 (A) and 0.05 (B) m/s face velocities versus particle diameter.

standards for single-use respirators (*Federal Register*, 25 March 1972) allow maximum initial pressure drop, at flow of 85 L/min, of 120 N/m^2 (1.2 cm of water), equivalent to 52 N/m^2 at our flow of 37 L/min, assuming the pressure drop is proportional to the flow rate. The lower pressure drops we measured for conditions in which the materials were not fully taped were due to the flow through leakage paths, reducing the resistance. Such low resistance could alert the wearer to the lack of protection and produce some compensating adjustment of the material to reduce the leakage.

From the coefficients of variation (standard deviations divided by means) for the cotton shirt and the toweling, we noted that errors in concentration determination probably were dominant, as these coefficients of variation are not far from the 0.06 value predicted by error analysis for the concentration determinations alone. The coefficient of variation for the handkerchief fully taped is higher than expected, suggesting that some of the variation came from differences among samples of the material itself. The fully taped masks also gave higher coefficients of variation than expected, probably indicating that the lower concentrations (due to their low penetrations) were measured with greater inaccuracy, in percentage terms. Those situations for which the corners were taped only or where the mask was held on with the strap(s) provided had coefficients of variation not greatly different from the corresponding fully taped condition values.

One goal of these measurements was to estimate leakages. Table III gives the material, the number of layers, the mean penetrations for the conditions in which the materials were held on with tape at the corners or by the straps provided, the mean penetration for the fully taped condition, and the estimates of the leakages and the confidence intervals for the leakages. The calculation of leakages was done using a formula developed as follows: the mass collected on the downstream filter (corrected for a few percent loss due to traversal through the manikin) is the product of the concentration (c) downstream, the total volume rate of flow (Q_T) and the time (t) and is equal to the indicated combination of upstream concentration (c_o), mean penetration ($\overline{Pn}$) and leakage flow rate (Q_L):

$$c\,Q_T t = c_o\,[\overline{Pn}\,(Q_T - Q_L) + Q_L]t \qquad (3)$$

which can be shown to give a ratio of leakage flow to total flow of:

$$Q_L / Q_T = [(c / c_o) - \overline{Pn}] / (1 - \overline{Pn})\,. \qquad (4)$$

Equation (4) indicates that the inferred leakage ($c / c_o - \overline{Pn}$) must be corrected by one minus the penetration of the material itself ($1 - \overline{Pn}$). This assumes that the penetration of the fabric itself under these conditions is the same as under the fully taped conditions, an assumption that is only approximately true. The leakage estimates were calculated by using Equation (4). They are shown in Table III as the mean leakage values. The confidence intervals were first determined for the difference $c/c_o - \overline{Pn}$ using standard statistical techniques that do not assume that both means have the same variance. The confidence intervals thus determined were then expanded by the factor $1/(1 - \overline{Pn})$, and these values are given in the last column of the table. The mean leakages for the household materials ranged from 18 percent to 63 percent, for the conditions in which these were held to the face by having the corners only taped. The masks when strapped on gave mean leakages of 17 percent and 33 percent. The nylon hosiery material held the handkerchief well enough to the face to reduce the leakage to about 5 percent. Most significantly, the nylon hosiery material held the commercial mask to the face so well that its leakage was reduced from about 17 percent to 0 percent, suggesting the incorporation of such nylon material in commercial masks to form a particularly effective combination for respiratory protection.

From the pressure drops measured with the masks on the manikin at 37 L/min flow and from the measurements made in our earlier study, one can infer the filter area of the masks and materials. The earlier measurements were interpreted by using a linear fit to the values of drag (pressure drop per unit

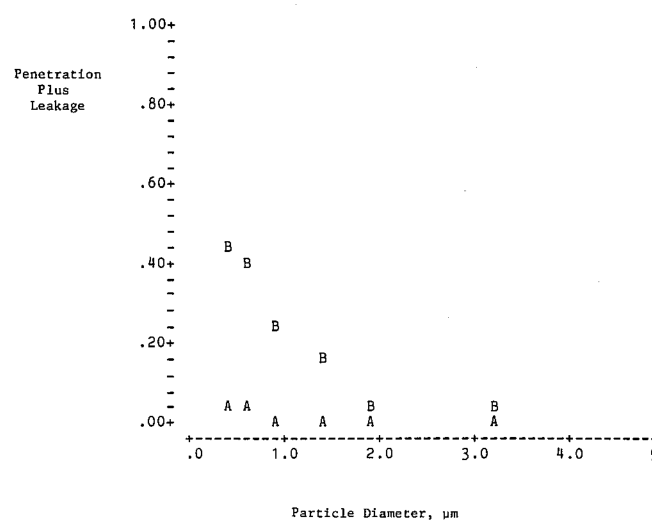

Figure 5 — Estimated penetration plus leakage of 3M #8710/nylon hosiery combination at 50 Pa pressure drop at 0.015 (A) and 0.05 (B) m/s face velocities versus particle diameter.

face velocity) versus face velocity. From the regressions, we derived the inferred face velocity (V) and inferred area (A). The values for the shirt and handkerchief materials inferred from the flow resistance ranged from 0.015 to 0.021 m^2.

A measurement of the assumed effective breathing area of the material was done for the white handkerchief and Oxford shirt material by the following procedure: The respective masks were fully taped to the manikin's face. An assumed effective breathing zone was traced out with a marker. The mean value for the area estimates for the shirt and handkerchief materials was 0.013 m^2 with a range of .0096 to .0142 m^2.

The effective surface area measurement of the 3M mask #8710 was conducted in a slightly different fashion. Due to the approximately hemispherical form of the 3M mask it was not possible to trace out and measure an effective surface area. The problem was solved by determining the ratio of mask area to mask weight. A square of approximately 2 cm × 2 cm was taken. The area of the 2" × 2 cm" square was 425 mm^2 as measured by an image analyzer system. From the ratio of the weight of this piece to the weight of the mask, the surface area of the mask was calculated to be 0.021 m^2; area calculated from the pressure drop data was 0.024 m^2.

Table IV shows values which can be used for a comparison between the tests performed on the manikin and the tests done earlier, using the materials in filter holders in an aerosol test loop, as the first phase of this project. Given are the penetrations expected from the previous set of measurements, which determined the quality factor [Equation (1)] for the materials. The quality factors change as face velocity and particle size change. They were determined previously at a particle diameter of 1.9 μm, a close approximation to the 1.8 μm droplets used in the manikin tests, and at 0.015, 0.05, and 0.15 m/s face velocities. The expected penetrations are calculated at the one velocity immediately above and below the inferred face velocity. The penetration measured on the manikin was between the two estimates for the 3M mask and the toweling, but it fell below both estimates for the shirt material and the handkerchief. (The estimates are made for the dry material; penetration estimates based on the wet material values from the earlier work would have been higher still for the shirt and the handkerchief.)

Discussion

Extrapolation to Other Conditions

In designing respirators for emergency use, one may want to aim for a pressure drop of at least 50 N/m^2, near the upper end of the range for comfortable use. High pressure drop is desirable because collection efficiency increases with pressure drop, other things being equal. Its disadvantage is the difficulty the wearer experiences in breathing. The designed mask's behavior would be more accurately predicted from our results if the face velocity were within the range studied (0.015 to 0.15 m/s); one can design the thickness of the material (and to a lesser extent the area) to achieve a given pressure drop. A flow rate near 37 L/min might well be used for design. We discuss next how these data can be extrapolated to such a design.

Two limits for the relationship between the leakage and the pressure drop are (a) that the flow in the leak is nearly laminar and depends proportionately on the pressure drop:

$$Q_L = k' (\Delta P) \tag{5}$$

or (b) that the flow in the leak and its vicinity is nearly potential flow, with the velocity and thus volume rate of flow depending on the square root of the pressure drop:

$$Q_L = k'' (\Delta P)^{1/2} \tag{6}$$

In the first case, as pressure drop increases, the leakage flow ratio $[Q_L/(Q_T - Q_L)]$ will stay constant, because the fabric flow $(Q_T - Q_L)$ is also proportional to pressure drop. In the second case, as pressure drop increases, the leakage flow ratio will decrease. In the analysis that follows, we chose a design pressure drop of 50 Pa and used the pessimistic assumption that the leakage is proportional to pressure drop.

To estimate the penetration of the fabrics/materials we used the quality factors determined in our previous study,[1] using those for 0.015 and 0.05 m/s, as the velocities inferred from our current work were between these two values. Penetration can be estimated from the quality factors using:

$$Pn = exp\,(-q\,\Delta P) \tag{7}$$

We set ΔP = 50 Pa. If L^* is the leakage fraction (Q_L/Q_T), then the total of leakage plus penetration is

$$c/c_o = (1-L^*)exp(-50q)+L^* \tag{8}$$

The results of three of these analyses are shown in Figures 3, 4, and 5. The values assuming the quality factors for 0.015 m/s are marked "A" and those for 0.05 m/s are marked "B".

Figure 3 shows the results for the 3M mask #8710 according to this extrapolation. As the mask gets quite efficient, for the larger particles, what gets through becomes equal to the leakage, 0.17. The shirt material is expected to offer little protection, largely due to the leakage around the seal to the face. The towel is expected to do somewhat better; however, its performance is also seriously limited by leakage. The handkerchief alone also did poorly at providing respiratory protection, but the handkerchief held on with the nylon hoisery material performed better, as shown in Figure 4. Even so, the reduction of concentration of 1-μm diameter particles is not impressive, being roughly a reduction of 20 to 60 percent. Very significant reductions are shown in Figure 5, where the expected behavior of the 3M #8710 mask held with the nylon hosiery is shown. Twenty percent or less of 1-μm diameter particles would be expected to reach an individual wearing this combination, the leakage having been reduced essentially to zero.

Implications for Improved Designs

The measurements indicated that the nylon hosiery did not itself collect particles, but it served to reduce dramatically the leakage through the seal of the other materials to the face, especially for the commercial mask. The incorporation of material such as panty hose to fix commercial masks to the face is likely to be an improvement over the straps now used, and this applies whether the masks are used routinely or only in emergency situations.

It is important to note that under conditions in which the nylon hosiery pulled the fabrics against the lips of the manikin, the filtration area was greatly reduced and the flow resistance became unacceptably high (10 to 100 times higher).

Having reduced the leakage to nearly zero percent with the use of the panty hose material as the method of holding the mask to the face, the limiting factor becomes the penetration of the material. The commercial materials tested showed appreciable penetration of particles of 1 μm diameter and smaller. Some commercial respirators allow less penetration. However, glass fiber filters are available commercially that allow much less than one percent penetration of the most penetrating particle size (near 0.3 μm diameter). Such filters can be used instead of, or as a supplementary layer for, the commercial mask material. If they were used as the front layer, then the second layer could be designed to assure that the glass fibers themselves, if dislodged, would not reach the wearer. If the flow resistance were too high for such a design, it could be reduced by increasing the filter area and by reducing the thickness of the layers used, given the extremely high efficiency of the glass fiber filter material. In practice, the glass fiber material might be placed as the central layer in a three-layer combination, to keep the glass fiber filter from being damaged.

Conclusions

The leakage through gaps in the seals of the materials to the face of the manikin was so substantial as to lessen substantially the effectiveness of the household fabrics studied as means of expedient respiratory protection: cotton/polyester shirt material, toweling, handkerchief material. Leakage around the commercial respirator mask was estimated to be about 1/6 of the flow and was about 1/3 of the flow for the surgeon's mask. The combination of the nylon hosiery material (panty hose) and the handkerchief should reduce concentrations by a factor of two or more for particles larger than about 2 μm in diameter. The use of the nylon hosiery material with the commercial respirator mask studied would reduce concentrations of 2-μm particles to about 2 percent or less of their original values, and perform even better for larger particles. The nylon hosiery material would also allow the surgeon's mask studied to approach the efficiency it had when fully taped to the manikin's face. Thus, some expedient methods of respiratory protection can be expected to produce substantial decreases in the amount of particulate material inhaled during emergency situations. Further, the modifications suggested for commercial masks now used routinely in industrial hygiene offer the potential of reducing to a few percent or less the amount of particulate material inhaled by workers wearing such masks.

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References

1. **Cooper, D.W., W.C. Hinds and J.M. Price:** Emergency Respiratory Protection with Common Materials. *Am. Ind. Hyg. Assoc. J. 44*:1-6 (1983).
2. **Guyton, H.G. and F.T. Lense:** Methods for Evaluating Respiratory Protective Masks and Their Component Parts. *A.M.A. Arch. Indust. Health 14*:246-249 (1956).
3. **Guyton, H.G., H.M. Decker and G.T. Anton:** Emergency Respiratory Protection Against Radiological and Biological Aerosols. *A.M.A. Arch. Ind. Health 20*:91-95 (1959).
4. **Leidel, N.A.:** Performance of Faceseal Fit Tests for Respiratory Protection Programs. Sc.D. Thesis, Department of Environmental Health Sciences, Harvard School of Public Health, Boston, MA (1979).
5. **Barghini, R.J. and D.P. Wilmes:** Performance Studies for Leakage of Half Mask Respirators, Comments - Standards Completion Project Ketone Hearings Inflationary Impact, Reference #13. Submitted to the Public Record at the U.S. Department of Labor, Occupational Safety and Health Administration, by the 3M Company, Washington, DC (December 1975).
6. **Silverman, L., T. Plotkin, L.A. Sawyer, and A. Yancey:** Air Flow Measurements on Human Subjects With and Without Respiratory Resistance at Several Work Rates. *Arch. Ind. Hyg., Occup. Med. 3*:461 (1951).
7. **Cooper, D.W., W.C. Hinds, J.M. Price, R. Weker, and H.S. Yee:** Expedient Methods of Respiratory Protection: II. Leakage Tests. Report NUREG/CR-2958, SAND82-7084, Sandia Laboratories, Albuquerque, NM (March 1983).

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